boron in glazes

by Matt Katz

Boron is one of the most, if not the most, misunderstood material in ceramics but it doesn't need to be. What exactly does it do? Where does it come from? How should we use it? These questions permeate the mysteries of boron but are easily answered.

Define the Terms

Boron: A low-temperature glass former.

Fluxes: The materials in a glaze that lower the melting temperature of the glass formers. They are also called modifiers as they modify the melting temperature of a glaze. Fluxes come in two forms: the alkalis (lithium, sodium, and potassium) and the alkaline earths (magnesium, calcium, strontium, barium, and zinc).

Frit: A powdered glass that can be either a part or the majority of a glaze. A frit is made to a specific chemical composition, batched, melted, cooled, crushed, and ground into a powder.

Glass Former: Material in a glaze that makes up the physical body, the glass network, of the glaze. This is predominately silica, but usually also includes alumina and may include boron in increasing amounts as firing temperature is lowered.

Intermediate: Materials that perform similarly to the major group of glass formers and modifiers but also contain properties of other groups. For example, iron functions predominately as a colorant, but in heavy concentrations can play the role of a flux.

Glass Former or Flux?

Boron is very basic in function and it performs in a predictable manner. However, boron usage in the US for the last 50 plus years has been dominated by Gerstley borate, a raw material that is prized for its unpredictability. This has left at least a couple generations of ceramists with varying levels of confusion about the true nature of boron and a collection of recipes that don't work without this particular material.

Boron is found primarily in Turkey, as an element in the mineral borax ($Na_2O{\bullet}3B_2O_3{\bullet}10H_2O$), and California (Boron, California, to be specific), where the largest mine in the state produces half of the world's boron.

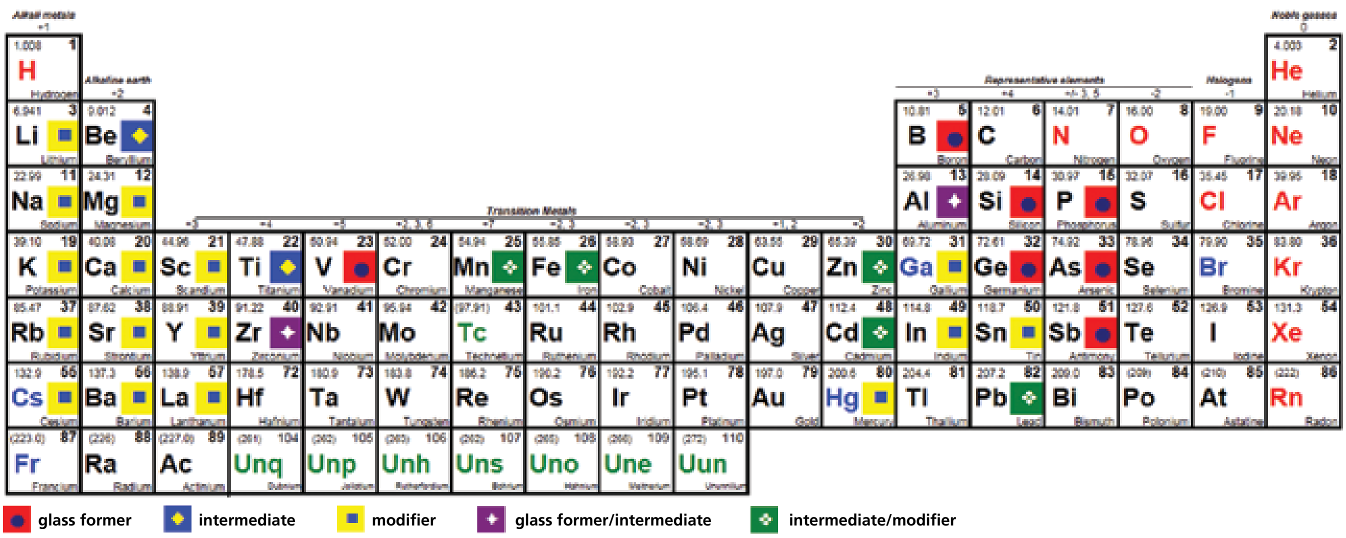
All glazes are based on only eleven oxides. These are the oxides of silicon, aluminum, lithium, sodium, potassium, magnesium, calcium, strontium, barium, zinc, and boron. There are others, but they are all relegated to the role of colorants, additives, or the relatively unused, such as the dreaded lead. These basic eleven elements make up 99% of glazes. The first ten can be simplified further into two groups—glass formers and fluxes. This leaves us with boron. Which is it, a glass former or a flux?

If you look at the version of the periodic table of the elements below, as used by glass scientists, boron is grouped with silicon and four other glass formers. It is above aluminum, which can substitute, within limits, for silica in a glass network.

All of the fluxes (except for zinc) are found in the first two columns of the table. They are the alkalis in the first column and the alkaline earths in the second. The elements in each column act similarly to each other and slightly different than the elements in the other column, yet all are fluxes. The function of true fluxes is to lower the melting temperature of glass formers. In the process, fluxes also influence color, strength, and the chemical and mechanical durability of glazes.

Historically, many have declared that boron is a flux because we use it to make glazes melt at low (cone 04) and mid-range (cone 6) temperatures. Here's where the confusion comes from. The fact is that boron is a glass former. We know this because pure boron oxide will make a glass on its own, just like pure silica will. Where boron differs from silicon is that boron oxide forms a glass at a dramatically lower temperature than silica.

All glazes require silica, and it is by leaps and bounds the most prevalent material in all glazes, regardless of temperature or type. Silica is the second most abundant material on earth after iron, making it cheap and plentiful. Boron, on the other hand, is a minor player. Boron is not pragmatic as a primary glass former for many reasons; material sources are all limited for reasons such as solubility, common availability, and cost. There are no glazes that are composed exclusively of boron; it is, at best, an accessory. Yet understanding boron for mid- and low-temperature glazes (even high-temperature), is very useful.



Periodic Table of Elements—oxide glass forming classification.

Sources

For many years, the major source of boron has been Gerstley borate. This is a naturally occurring deposit of the minerals colemanite ($2CaO{\bullet}3B_2O_3{\bullet}5H_2O$), ulexite ($NaCaB_5O_9{\bullet}8H_2O$) and bentonite ($3Al_2O_3{\bullet}SiO_2{\bullet}H_2O$). Gerstley borate is an exciting material for ceramists as the two borate materials (colemanite and ulexite) melt at different times in the firing, leading to the "breaking" effect of the glaze.

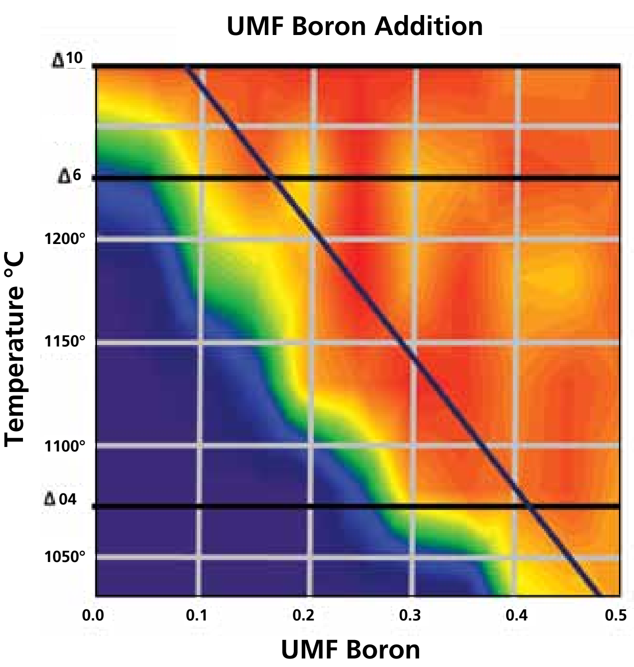
When it was feared that Gerstley's availability would be limited (the mine was closed for safety reasons) a variety of materials sold as Gerstley substitutes came onto the market. There are also two other types of borate materials: frits, and soluble sources. The soluble materials, boric acid ($B_2O_3{\bullet}3H_2O$) and borax, are very effective boron sources. The problem with these materials is they are very soluble in water, meaning that the boron dissolves in the water of the glaze. As glazes dry, the water is absorbed into the bisqued clay body rather than remaining in the glaze. This can change the melting performance of the body (over melting) and the glaze (under melting).

For this reason, frits are the favored sources for boron. Frits are wonderful materials as they provide all the boron required in a stable, minimally soluble form. Frits are essentially glazes that have been batched, melted, and then ground to a powder by the frit manufacturer. There are a huge number of frits out there, but in the US our palette is often limited to Ferro's 31XX series, including 3110, 3124, 3134, and 3195. Each of these frits does something different but they are all very simple and bring in various amounts of boron.

Boron and UMF

The function of silica, alumina, and fluxes are well understood in the unity molecular formula (UMF) or Seger formula, thanks to the work of R.T. Stull. However, boron, as a bit player, did not receive any attention in his work. All high-temperature glazes require silica, alumina, an alkaline earth, and an alkali. Boron is not required for a cone 10 glaze. At Alfred University, Dr. Bill Carty and I have put a lot of effort into defining how to best utilize boron from a UMF perspective. We believe that one can predict the amount of boron needed to make a glaze melt based on the desired firing temperature.

The graph on this page shows the amount of boron required at any temperature. The purple-blue areas are underfired, while the red/orange areas are very glossy. The vertical axis is temperature in celsius and the horizontal axis is UMF boron additions to a standard glaze. By finding the desired temperature and determining the position on the oblique line, you can figure out the corresponding required UMF boron level at that temperature. This chart applies from cone 06 to cone 10. As a general rule, we define the required amount of boron as an additional 0.1 mole (via UMF) of boron for every 50°C below cone 10 (1305°C). Boron is an exceptionally good material for adding to glazes as it makes glasses at lower temperatures that are just as strong and resistant to wear and chemical leaching as the best cone 10 glazes.



Boron Glaze Limits. The above chart indicates amounts of boron needed to make a glaze melt based on the desired firing temperature. Orange/red suggests a glossy melt, purple/blue areas indicate underfired surfaces.

Cone 10 to Cone 6—The First Step

A glaze temperature conversion is no easy feat. It takes knowledge and experience to successfully convert a glaze recipe that works at one temperature so it works as well at another. There are a lot of subtle factors in the chemistry of a glaze that dictate its color, texture, and performance. That said, here is a quick start with fast results, helped in part by boron.

1. Take a cone 10 glaze that you are fond of and mix three 100 gram batches of it.

2. Add Ferro frit 3124 to the cups: 5% to one, 10% to the second, and 15% to the third.

3. Apply each test recipe to its own flat test tile. Place each in a disposable unglazed clay run catcher.

4. Fire the tiles, propped at a 45° angle, to cone 6.

5. Select the glaze that ran the least in the kiln.

This is just a first step to adjusting your glaze to a lower temperature, but it should be a good starting place for creating a glaze that looks similar. By using a frit, you are introducing boron as a material that will not alter the basic nature of the glaze but will still contribute the boron needed to lower the firing temperature.

THE PERFECT CONE 04 GLOSS

Ferro Frit 3124	90 %
EPK Kaolin	10
	100 %

Add: 10% Zircopax for a white glaze

MATT AND DAVE'S CRAZE-FREE GLOSS

Cone 10

Whiting	5.42 %
Ferro Frit 3124	40.46
G200 HP	14.37
EPK Kaolin	27.20
Silica	12.55
	100.00 %